

# **FREQUENCY CORRECTION METHOD AND APPARATUS FOR CORRECTING SECULAR CHANGE**

## **BACKGROUND OF THE INVENTION**

### **5 1. Field of the Invention**

The present invention relates to a technique of correcting a frequency of an oscillator, and particularly to a technique of automatically correcting a frequency of a reference oscillator in a terminal of a mobile communication system using CDMA method or the like.

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### **2. Description of the Related Art**

In recent mobile communication, a high frequency band from 900MHz to several GHz has been used. Therefore, even though a TCXO (temperature compensated crystal oscillator) having high precision such as a frequency error of almost 3.0ppm is used as a reference oscillator, a frequency error of 3kHz or above can occur. Therefore, a frequency deviation caused by the frequency error of the reference oscillator occurs between a transmitter and a receiver. When the frequency deviation between the transmitter and the receiver is enlarged, a signal received in the receiver cannot be correctly de-modulated.

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When precision of TCXO used for the reference oscillator is heightened, the frequency deviation is lowered. However, the cost of a terminal is inevitably increased. Therefore, a technique has been conventionally proposed that the frequency deviation is lowered by adjusting a frequency oscillated by TCXO (For example, refer to Japanese Patent Application Publication No. H6-326740).

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Referring to FIG. 1, a conventional mobile terminal has antennas 501 and 514, receiver 502, de-modulator 503, decoder 504, RX-synthesizer 505, TCXO 506, D/A converter 507, controller 508, frequency error detector 509, coder 510, modulator 511, TX-synthesizer 512 and transmitter 513.

5 Receiver 502 converts a radio frequency signal transmitted from a base station (not shown) and received in antenna 501 to an intermediate frequency signal and transmits the intermediate frequency signal to de-modulator 503. Because receiver 502 uses a frequency signal obtained in RX-synthesizer 505 which uses a reference frequency of TCXO 506, a  
10 frequency of the intermediate frequency signal produced in receiver 502 includes an error based on an oscillation frequency error of TCXO 506.

De-modulator 503 de-modulates the intermediate frequency signal transmitted from receiver 502 and transmits obtained received base band signals (RX-I, RX-Q) to decoder 504 and frequency error detector 509.

15 Decoder 504 decodes the received base band signals and transmits obtained received DATA to a circuit (not shown) of a subsequent stage in synchronization with clock.

Frequency error detector 509 detects a frequency error  $\Delta f$  from the received base band signals, for example, by measuring a difference in phase  
20 between slots, and transmits the frequency error  $\Delta f$  to controller 508.

Controller 508 generates a frequency error compensating signal (hereinafter, simply named "control signal")  $DV_c$  lowering the frequency error  $\Delta f$  to a predetermined value or below and transmits the control signal  $DV_c$  to D/A converter 507.

25 D/A converter 507 performs digital-to-analog conversion for the digital control signal  $DV_c$  and gives such an obtained control voltage  $V_c$  to TCXO

506.

In TCXO 506, an oscillation frequency of a crystal oscillator (not shown) is controlled in voltage by using the control voltage Vc. TCXO 506 gives an oscillation frequency obtained by the control to RX-synthesizer 505 and TX-synthesizer 512 as a reference frequency.

By performing the control of controller 508 for TCXO 506 so as to lower the frequency error  $\Delta f$  detected in frequency error detector 509 to the predetermined value or below, the reference frequency in TCXO 506 is synchronized with a received signal and is stabilized.

RX-synthesizer 505 generates a frequency signal of a desired frequency from the reference frequency and transmits the frequency signal to receiver 502 and de-modulator 503.

TX-synthesizer 512 generates a frequency signal of a desired frequency from the reference frequency and transmits the frequency signal to transmitter 513 and modulator 511.

Coder 510 receives Transmit DATA synchronized with clock from a circuit (not shown) at a preceding stage, codes the Transmit DATA and transmits the coded Transmit DATA to modulator 511 as transmit base band signals (TX-I, TX-Q).

Modulator 511 modulates the intermediate frequency signal with the transmit base band signals and then transmits it to transmitter 513.

Transmitter 513 converts the intermediate frequency signal transmitted from modulator 511 to a radio frequency signal and transmits the radio frequency signal to a base station (not shown) through antenna 514.

Referring to FIG. 2, controller 508 has register 601, adder 602 and multiplier 603.

Multiplier 603 multiplies a signal of the frequency error  $\Delta f$  by a coefficient "a" and transmits thus obtained signal to adder 602. Adder 602 adds an output of register 601 and an output of multiplier 603 with a predetermined adding polarity and transmits an obtained value to register 5 601. In the example of FIG. 2, adder 602 subtracts the output of multiplier 603 from the output of register 601.

Register 601 temporarily stores and delays an output of adder 602 and transmits the output to D/A converter 507 and adder 602. A summing circuit is composed of register 601 and adder 602, and outputs of multiplier 10 603 are summed in the summing circuit. A control signal DVc indicates a result of the summed outputs.

Referring to FIG. 3, the relation between the control voltage Vc given to TCXO 506 and an amount of change in the reference frequency based on the control voltage Vc can be expressed by a substantially straight line. 15 Accordingly, when the adding polarity of adder 602 is correctly selected so as to lower the frequency error, the reference frequency in TCXO 506 can be converged so as to be synchronized with the received signal transmitted from a base station (not shown).

The configuration described above is a typical example of a frequency 20 correction apparatus in a conventional mobile terminal. As described above, in the conventional mobile terminal, a frequency error is detected according to some method, the frequency error is given to a reference oscillator, and a reference frequency is corrected.

However, there exist the following problems in the above-described 25 prior art.

In CDMA mobile communication represented by IS95 of the United

States, a base station superposes frequency-spread signals of a plurality of channels on the same frequency. Further, a plurality of base stations use the same frequency, and each base station transmits signals of a plurality of channels of different spreading codes at the same frequency.

5 Therefore, electric waves are received in the mobile terminal with a plurality of channels transmitted from a plurality of base stations existing by mixture in the same frequency. In CDMA, this considerably differs from an analog method and a digital method of TDMA. Each of channels existing by mixture in the same frequency is distinguished by using a spreading code  
10 used for the corresponding frequency spreading.

Only when the mobile terminal performs complicated types of processing such as base station search, synchronization, frequency despread and the like, the mobile terminal can extract a signal addressed to itself from signals of a plurality of channels existing by mixture in the same  
15 frequency. Further, only when the mobile terminal extracts a signal addressed to itself, the mobile terminal can detect an error (frequency deviation) between a frequency of the signal addressed to itself and a reference frequency of itself. Accordingly, in the mobile terminal of the CDMA mobile communication, unless the complicated processing are  
20 correctly performed in de-modulator 503, no frequency error can be detected in frequency error detector 509.

Further, to perform normally the complicated processing such as base station search, synchronization, frequency despread and the like, an error of the reference frequency is required to be substantially small. To perform  
25 normally the complicated processing, a severe condition is given to the reference frequency in TCXO 506 that a deviation between the reference

frequency and a frequency of a signal transmitted from a base station is, for example, within  $\pm 3.0\text{ppm}$ .

When the reference frequency in TCXO 506 does not satisfy this condition, frequency error detector 509 cannot detect the frequency error,  
5 and the mobile terminal cannot correct the reference frequency.

Therefore, in order to start the correction of the reference frequency in the mobile terminal, even in condition that the correction to be performed by giving the frequency error detected in frequency error detector 509 to TCXO 506 is not performed, TCXO 506 is required to generate a reference  
10 frequency having precision which satisfies a severe condition such as with  $\pm 3.0\text{ppm}$ .

As causes of changing a reference frequency oscillated by TCXO 506 and generating error, there are temperature and time changes.

As to the change of the reference frequency due to change of  
15 temperature, for example, even though an oscillator with the highest performance currently available is used as TCXO 506, there is a probability that a frequency change such as within  $\pm 2.0\text{ppm}$  in the worst case occurs in a temperature range of  $-35^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$  in which the mobile terminal should be guaranteed to be able to be operated.

20 In FIG. 4, theoretical values of the change of the oscillation frequency due to change of temperature are shown by a solid line on condition that no secular change exists. In the example of FIG. 4, in case of no secular change, the oscillation frequency satisfies the condition that an amount of change is within  $\pm 3.0\text{ppm}$  in a range of  $-35^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$  centering around  
25  $25^{\circ}\text{C}$ .

In FIG. 5, a secular change of an oscillation frequency of a crystal

oscillator is exemplarily shown in which the oscillation frequency is lowered by 0.5ppm per year. Further, in order to show only influence of the secular change, influence of temperature is removed.

As shown in FIG. 5, even though the oscillation frequency of the crystal oscillator in TCXO 506 is correctly adjusted just before being shipped from the factory shipping time, when the crystal oscillator is used for a long term, the oscillation frequency changes due to a chemical change of the crystal oscillator. In the example of FIG. 5, the oscillation frequency becomes lower by 0.5ppm in one year, 2.5ppm in five years and 5.0ppm in ten years.

As shown in FIG. 6, in the oscillation frequency of the crystal oscillator, there is a short term change due to a temperature change superposing on a secular change gradually changing for a long term. As understood from FIG. 4, for example, the oscillation frequency changes due to influence of a temperature difference between night and daytime. When the crystal oscillator is placed out of doors in a cold area in winter, the crystal oscillator cooled to  $-10^{\circ}\text{C}$  or below is quite possible. When the crystal oscillator is placed in an automobile during daytime in midsummer, it is quite possible the crystal oscillator can become heated to  $60^{\circ}\text{C}$  or above.

Further, the temperature of a mobile terminal is changed in dependence on operation conditions. When the mobile terminal is set in a power-off state, because there is no heat generated due to electric power consumption, the mobile terminal is sufficiently cooled at a time just after power turn-on and is set at a low temperature. However, when time has sufficiently elapsed after power turn-on, even though the mobile terminal is set in a standby state, temperature of the mobile terminal is elevated by heat

generated due to electric power supply. Further, because a transmission amplifier is heated due to transmission of electric waves in a talking state, the mobile terminal is heated to a highest temperature. Furthermore, at a changing time of each state described above, there exists an unstable period in which temperature of the mobile terminal is transitionally changed. As described above, the oscillation frequency of the crystal oscillator of TCXO 506 frequently changes in a short period due to the temperature change.

In contrast, the oscillation frequency of the crystal oscillator is changed very slowly due to a secular change. For example, in a period of almost one month, a secular change of the oscillation frequency is very small and within range of a negligible error. However, like 2.5ppm in five years in FIG. 5, when a secular change in several years is observed, the oscillation frequency has undoubtedly changed due to the secular change.

In a short period, an amount of change in the oscillation frequency is within range of about  $\pm 2.0\text{ppm}$  due to the temperature change, and there is no problem in operation. However, in a long term, a secular change is added to the change of the oscillation frequency. Therefore, when four or five years have elapsed, an amount of change can be out of  $\pm 3.0\text{ppm}$ , denoting an allowable range. When the time has further elapsed, the probability of the amount of change placed out of  $\pm 3.0\text{ppm}$  is further heightened.

As described above, when the secular change of the crystal oscillator is left as it is, the reference frequency of TCXO 506 changes little by little, and the correction to be performed by giving the frequency error detected in frequency error detector 509 to TCXO 506 eventually cannot be performed. Therefore, when several years have elapsed after the shipping has begun,

there is a probability that operational failure will occurs in a large number of mobile terminals.

As one of the countermeasures, an initial value of the control signal DVc for TCXO 506 at a time just after power turn-on is, for example, set to a convergent value previously obtained at a time before power turn-off.

However, it is uncertain that temperature at the current time is almost the same as that at the previous time, and there is a probability that temperature at the current time considerably differs from that at the previous time.

Accordingly, in case of this counter measure, in dependence on the temperature difference, there is a probability that conditions will become worse than those in case of no adoption of this countermeasure, is not adopted.

## SUMMARY OF THE INVENTION

An object of the present invention is to provide frequency correction method and apparatus for always keeping a change in frequency of an oscillator due to a temperature change and a secular change within a proper range and to provide a mobile terminal in which a reference frequency can be always kept within a proper range.

To achieve the object, a frequency correction method according to the present invention is a frequency correction method for keeping a frequency of a controllable oscillator within a proper range and comprises first to third steps. In the first step, past control information for the oscillator is recorded. In the second step, a secular change of the frequency of the oscillator is calculated from the past control information. In the third step, new control information for correcting the calculated secular change is given to the

oscillator.

Further, a frequency correction apparatus according to the present invention is a frequency correction apparatus for keeping a frequency of a controllable oscillator within a proper range and has storing means and processing means. The storing means records past control information for the oscillator. The processing means calculates a secular change of the frequency of the oscillator from the past control information and gives to the oscillator new control information for correcting the calculated secular change.

Furthermore, a mobile terminal according to the present invention has receiving means, local signal generating means, a reference oscillator, de-modulating means, frequency error detecting means, summing means, storing means, processing means and integrating means. The receiving means receives an electric wave from a base station. The local signal generating means supplies an oscillating local signal to the receiving means. The reference oscillator generates a reference signal of a frequency which is a reference for generating the local signal in the local signal generating means. The de-modulating means de-modulates a desired received signal from the electric wave received by the receiving means. The frequency error detecting means detects a frequency error of the reference oscillator on a basis of the received signal de-modulated by the de-modulating means. The summing means sums frequency errors detected by the frequency error detecting means and produces fundamental control information for correcting the frequency error. The storing means records past control information for the reference oscillator. The processing means calculates a secular change of a frequency of the reference oscillator from the past control information.

The integrating means integrates the fundamental control information produced by the summing means and the secular change calculated by the processing means and gives to the reference oscillator new control information for correcting the frequency of the reference oscillator.

5            Preferably, the secular change may be calculated by using an approximate value obtained from an average of pieces of past control information.

            Further, preferably, a temperature at a time when the past control information is decided may be recorded in correspondence to the past control  
10 information, and the secular change of the frequency of the oscillator may be calculated from the past control information and the temperature.

            Furthermore, preferably, a relational expression of the past control information for temperatures placed within a predetermined range is decided according to approximation using discrete data of the past control information  
15 and temperatures, and the secular change may be calculated by using an approximate value which is obtained from the relational expression by setting a predetermined temperature of the predetermined range as a reference.

            The above and other objects, features, and advantages of the present invention will become apparent from the following description with reference  
20 to the accompanying drawings which illustrate examples of the present invention.

## BRIEF DESCRIPTION OF THE DRAWINGS

            FIG. 1 is a block diagram showing a conventional typical mobile  
25 terminal;

            FIG. 2 is a block diagram showing a controller shown in FIG. 1;

FIG. 3 is a graph showing an example of the relation between a control voltage and an amount of frequency change in a reference oscillator;

FIG. 4 is a graph showing an example of a temperature change of an oscillating frequency of a crystal oscillator used for the reference oscillator;

5 FIG. 5 is a graph showing an example of a secular change of an oscillating frequency of a crystal oscillator used for the reference oscillator;

FIG. 6 is a graph showing an example of a change, obtained by superposing a temperature change on a secular change, of an oscillating frequency of a crystal oscillator used for the reference oscillator;

10 FIG. 7 is a block diagram showing a mobile terminal according to an embodiment of the present invention;

FIG. 8 is a block diagram showing a controller shown in FIG. 7;

FIG. 9 is a view showing data recorded in an AFC-LOG; and

FIG. 10 is a flow chart showing the processing of both the renewal of  
15 the data of the AFC-LOG and the calculation of secular change correction data in a processing unit.

## EMBODIMENTS

An embodiment of the present invention will now be described with  
20 reference to the accompanying drawings.

As causes of changing a reference frequency of a mobile terminal of CDMA, there are a temperature change and a secular change of a crystal oscillator. When a change of the reference frequency combining the temperature change and the secular change can be placed within a  
25 predetermined allowable range (for example, within  $\pm 3.0\text{ppm}$ ), the mobile terminal can perform complicated processing such as base station search,

synchronization, frequency despread and the like. When such processing can be normally performed, the mobile terminal can perform a frequency correction operation by detecting an error between an extracted signal addressed to itself and the reference frequency of itself and giving the error to the reference oscillator.

When a crystal oscillator having some degree of precision is used, the temperature change among the temperature change and the secular change is placed within a predetermined temperature change range (for example, within  $\pm 2.0\text{ppm}$ ). Therefore, when the temperature change and the secular change are separated from each other and only the secular change is appropriately corrected, even though the mobile terminal is used for a long term, the reference frequency of the mobile terminal is not placed out of an allowable range.

Referring to FIG. 7, the mobile terminal has antennas 101 and 118, receiver 102, de-modulator 103, decoder 104, RX-synthesizer 105, TCXO 106, D/A converter 107, controller 108, frequency error detector 109, temperature sensor 110, A/D converter 111, timer 112, past data memory (AFC-LOG) 113, coder 114, modulator 115, TX-synthesizer 116 and transmitter 117.

Receiver 102 converts a radio frequency signal transmitted from a base station (not shown) and received in the antenna 101 to an intermediate frequency signal, and transmits the signal to de-modulator 103. Because receiver 102 uses a frequency signal obtained in RX-synthesizer 105 which uses a reference frequency of TCXO 106, a frequency of the intermediate frequency signal produced in receiver 102 includes an error based on an oscillation frequency error of TCXO 106.

De-modulator 103 de-modulates the intermediate frequency signal transmitted from receiver 102 and transmits received base band signals (RX-I, RX-Q) thus obtained to decoder 104 and frequency error detector 109.

Decoder 104 decodes the received base band signals and transmits received DATA thus obtained to a circuit (not shown) at a subsequent stage in synchronization with clock.

Frequency error detector 109 detects a frequency error  $\Delta f$  from the received base band signals, for example, by measuring a difference in phase between slots, and transmits the frequency error  $\Delta f$  to controller 108. A frequency of the received signal is set as a target frequency of the control for TCXO 106, and the frequency error  $\Delta f$  denotes a difference between the reference frequency generated in TCXO 106 and the target frequency.

Temperature sensor 110 measures a temperature  $T_e$  in the neighborhood of TCXO 106 and transmits the temperature  $T_e$  to A/D converter 111.

A/D converter 111 performs analog-to-digital conversion for an analog signal of the temperature  $T_e$  and transmits temperature data  $D_{Te}$  thus obtained to controller 108.

Timer 112 transmits time information  $T$  to controller 108.

Past data memory (AFC-LOG) 113 records values of a plurality of past control signals  $DV_c$  obtained in controller 108, and pieces of time information  $T$  and pieces of temperature data  $D_{Te}$  respectively at times when the values are obtained. The control signals  $DV_c$  denotes control information used for controller 108 to control the frequency of TCXO 106. Because the controllable frequency of an oscillator is voltage normally controlled, each past control signal  $DV_c$  denotes information indicating a controlled voltage.

Controller 108 corrects a secular change of the reference frequency according to the data, the temperature data DTe and the time information T recorded in AFC-LOG 113, and the frequency error  $\Delta f$ . Further the controller 108 generates a frequency error compensating signal (hereinafter, simply named "control signal") DVc lowering the frequency error  $\Delta f$  to a predetermined value or below and transmits the control signal DVc to D/A converter 107.

D/A converter 107 performs digital-to-analog conversion for the digital control signal DVc and gives a control voltage Vc thus obtained to TCXO 106.

TCXO 106 voltage controls an oscillation frequency of a crystal oscillator (not shown) according to the control voltage Vc and gives an oscillation frequency obtained by the control to RX-synthesizer 105 and TX-synthesizer 116 as a reference frequency.

By performing the control of controller 108 for TCXO 106 so as to lower the frequency error  $\Delta f$  detected in frequency error detector 109 to the predetermined value or below, the reference frequency in TCXO 106 is synchronized with the received signal and is stabilized.

RX-synthesizer 105 generates a local frequency signal oscillated at a desired frequency from the reference frequency and transmits the local frequency signal to receiver 102 and de-modulator 103.

TX-synthesizer 116 generates a local frequency signal oscillated at a desired frequency from the reference frequency and transmits the local frequency signal to transmitter 117 and modulator 115.

Coder 114 receives Transmit DATA synchronized with clock from a circuit (not shown) at a preceding stage, codes the transmit DATA and

transmits the coded transmit DATA to modulator 115 as transmit base band signals (TX-I, TX-Q).

Modulator 115 modulates the frequency signal with the transmit base band signals and transmits an obtained intermediate frequency signal to  
5 transmitter 117.

Transmitter 117 converts the intermediate frequency signal transmitted from modulator 115 to a radio frequency signal and transmits the radio frequency signal to a base station (not shown) through antenna 118.

Referring to FIG. 8, controller 108 has adders 201 and 203, registers  
10 202 and 205, multiplier 204 and processing unit 206.

Multiplier 204 multiplies a signal of the frequency error  $\Delta f$  by a coefficient "a" and transmits an obtained signal to adder 203.

Adder 203 adds an output of register 202 and an output of multiplier 204 with a predetermined adding polarity and transmits an obtained value to  
15 register 202. In the example of FIG. 8, adder 203 subtracts the output of multiplier 204 from the output of register 202. Register 202 temporarily stores and delays an output of adder 203 and transmits the output to adder 201 and adder 203. Summing circuit 207 is composed of multiplier 204, register 202 and adder 203, and frequency errors  $\Delta f$  are summed in  
20 summing circuit 207. A signal obtained by summing the frequency errors  $\Delta f$  denotes a signal indicating fundamental control information for correcting another frequency error  $\Delta f$ .

Adder 201 adds the output of register 202 and an output of register 205 with a predetermined adding polarity and transmits an obtained value to  
25 D/A converter 107 and processing unit 206 as the control signal DVc. Because the oscillating frequency of the crystal oscillator is lowered due to

the secular change, adder 201 subtracts the output of register 205 denoting correction data of the secular change from an output of summing circuit 207.

Processing unit 206 writes data of the control signal DVc in AFC-LOG 113 with a temperature Te and time information T at this time and renews data of AFC-LOG 113. Thereafter, processing unit 206 calculates secular change correction data according to pieces of data recorded in AFC-LOG 113 and transmits the secular change correction data to register 205. Register 205 stores the secular change correction data and transmits the secular change correction data to adder 201.

Further, processing unit 206 may take temperature data DTe, the time information T and the control data DVc at the current time into consideration. Furthermore, when processing unit 206 calculates the secular change correction data, processing unit 206 may further take operation mode information of the mobile terminal into consideration. The operation mode information denotes information indicating an operation mode of the mobile terminal such as a standby mode, a call mode, a talking mode or the like.

Refer to FIG. 9, temperatures Te(i), control signals DVc(i) and time information T(i) (i is an integer, and  $i = 0$  to  $N-1$ ) at past N times are stored in N address areas of AFC-LOG 113 from an address "0000" to an address "000(N-1)". In this example, an example of storing pieces of data from the address "0000" is shown for convenience. However, the present invention is not limited to this. When a leading address of a data storing area differs from "0000", the address of FIG. 9 may be considered as an offset value.

Refer to FIG. 10, processing unit 206 initially calculates an address n to be renewed at a subsequent time (step 401). The address n to be renewed is expressed by an integer cyclically changing at modulo N. When

unity is added to a preceding value, the address n to be renewed at this time is obtained, and "0" is obtained after "N-1". That is, the address n is obtained according to the residue calculation to modulus n.

Thereafter, processing unit 206 writes a current temperature  $T_e$ , a value of the control signal  $DV_c$  and a current time  $T$  in the area of the address n and renews data of AFC-LOG 113 (step 402). Then, processing unit 206 calculates new secular change correction data  $DV_{comp}$  according to data recorded in AFC-LOG 113 (step 403).

An example of the calculation of the new secular change correction data  $DV_{comp}$  will be described.

When there is defined a control signal  $DV_{ideal}$  setting an amount of frequency change to zero in an ideal state in which no secular change exists, the secular change correction data  $DV_{comp}$  is expressed as follows.

$$D V_{comp} = D V_{ideal} - \frac{1}{N} * \sum_{i=0}^{N-1} D V_c(i) \quad (1)$$

That is, a value obtained by subtracting an average value of past control signals  $DV_c(0)$  to  $DV_c(N-1)$  from the ideal control signal  $DV_{ideal}$  is set as the new secular change correction data  $DV_{comp}$ . As described above, when an average value of a plurality of (N) past control signals  $DV_c$  is subtracted, a change due to the temperature change can be removed, and a change due to the secular change can be extracted. When the secular change is subtracted from the ideal control signal  $DV_{ideal}$ , secular change correction data can be calculated.

There are various methods of determining a renewal cycle or a renewal time of AFC-LOG 113 to preferably remove a change due to the secular change. For example, as a simple method, data of AFC-LOG 113 is

renewed at equal intervals, for example, by performing the renewal at a predetermined time every day during one month. In this method, almost thirty pieces of data can be accumulated in one month, and the temperature change can be preferably removed. The renewal time of each day is not set to a time at which the highest temperature or the lowest temperature of the day tends to be obtained, but is set to a time at which an average temperature of the day tends to be obtained.

As described above, in this embodiment, processing unit 206 records a plurality of past control signals DVc in AFC-LOG 113, removes a change due to the temperature change from a control signal DVc by averaging the past control signals DVc, and extracts and corrects a change due to the secular change. Accordingly, the change due to the secular change can be accurately and stably corrected. Further, even though the mobile terminal is used for a long term, the reference frequency can be kept within an allowable range.

Further, because the reference frequency can be always kept within the allowable range, de-modulator 103 can normally perform complicated processing such as base station search, synchronization, frequency despread and the like, and frequency error detector 109 can detect a frequency error. Accordingly, the correction of the reference frequency can be always performed by giving the frequency error to TCXO 106.

In this embodiment, the secular change correction data DVcomp is calculated by subtracting the average value of the past control signals DVc from the ideal control signals DVideal. However, the present invention is not limited to this, and there exist other various methods of calculating the secular change correction data DVcomp.

For example, the temperature  $T_e$  may be used to calculate the secular change correction data  $DV_{comp}$ . In this case, it is assumed that the relation between the temperature  $T_e$  and the control signal  $DV_c$  can be approximated by a linear equation within a predetermined temperature range, and an

5 approximate linear equation is determined.

The approximate linear equation is set as follows.

$$DV_c = AT_e + B \quad (2)$$

A and B are calculated according to the least squares method by using

10 discrete data composed of a plurality of past temperatures  $T_e$  and a plurality of past control signals  $DV_c$ . That is, A and B minimizing

$$\sum_{i=0}^{N-1} E^2(i) = \sum_{i=0}^{N-1} [DV_c(i) - AT_e(i) - B]^2 \quad (3)$$

are calculated from

$$A = \frac{N * \sum_{i=0}^{N-1} \{DV_c(i) * T_e(i)\} - \sum_{i=0}^{N-1} DV_c(i) * \sum_{j=0}^{N-1} T_e(j)}{N * \sum_{i=0}^{N-1} \{T_e(i)\}^2 - \left\{ \sum_{i=0}^{N-1} T_e(i) \right\}^2} \quad (4)$$

$$15 \quad B = \frac{\sum_{i=0}^{N-1} DV_c(i) * \sum_{j=0}^{N-1} \{T_e(j)\}^2 - \sum_{i=0}^{N-1} T_e(i) * \sum_{j=0}^{N-1} \{DV_c(j) * T_e(j)\}}{N * \sum_{i=0}^{N-1} \{T_e(i)\}^2 - \left\{ \sum_{i=0}^{N-1} T_e(i) \right\}^2} \quad (5)$$

by using N pieces of data recorded in AFC-LOG 113.

Here, when an ideal temperature  $T_{ideal}$  (for example, 25°C) used as a reference is defined to correct the secular change, the secular change correction data  $DV_{comp}$  is expressed as follows.

$$D V_{comp} = D V_{ideal} - A T e_{ideal} - B \quad (6)$$

That is, a value obtained by subtracting a value of the approximate linear equation determined according to the least squares method at the ideal temperature  $T_{ideal}$  from the control signal  $DV_{ideal}$  setting an amount of frequency change to zero in an ideal state in which no secular change exists is set as secular change correction data  $DV_{comp}$ . Processing unit 206 writes the secular change correction data  $DV_{comp}$  into register 206.

An example will be described hereinafter.

Referring to FIG. 4, theoretical values of the temperature change of the oscillating frequency in the state in which no secular change exists are indicated by a solid line. As understood from this solid line, an amount of frequency change with respect to temperature can be expressed by a substantially straight line within a temperature range actually used such as a range of  $-0^{\circ}\text{C}$  to  $+50^{\circ}\text{C}$ . Further, as shown in FIG. 3, an amount of frequency change with respect to control voltage  $V_c$  can be expressed by an substantially straight line within an actual control range such as a range of  $-7\text{ppm}$  to  $+6\text{ppm}$ . Accordingly, it should be appreciated that the approximate linear equation (2) is effective in an actual use environment.

Further, in FIG. 4, an amount of frequency change obtained after the mobile terminal is used for several years is plotted by “\*”. As understood from FIG. 4, these plotted symbols indicate discrete values. However, when an approximate linear equation is calculated from the discrete values according to the least squares method, the amount of frequency change can be expressed by a straight line shown in FIG. 4 by a dotted line.

When the ideal temperature is set to  $25^{\circ}\text{C}$ , a difference in an amount of frequency change at  $25^{\circ}\text{C}$  between the straight line derived from the

approximate linear equation (2) and the dotted line indicates a value to be corrected as the secular change. A control voltage corresponding to this value is digitalized and is set as a control signal DVcomp.

When the calculation of the secular change correction data DVcomp described above is used, processing unit 206 records a plurality of past control signals DVc and the temperatures Te at those times in AFC-LOG 113, approximately expresses an amount of frequency change with respect to temperature by a linear equation from discrete values of data of AFC-LOG 113, removes a change due to the temperature change from the control signal DVc and extracts and corrects a change due to the secular change. Accordingly, even though the temperature environment in the use of the mobile terminal is fluctuated or biased, the change due to the secular change can be accurately and stably corrected by using the ideal temperature as a reference, and the reference frequency can be kept within the allowable range even after the mobile terminal is used for a long term. Therefore, for example, even though a mobile terminal used in midwinter in a cold area such as the central part of Hokkaido, Japan is brought to a high temperature area such as Okinawa, Japan because of travel or a business trip, the reference frequency of the reference oscillator can be kept within the allowable range, and the mobile terminal can be normally used.

Further, in this embodiment, as an example, a method is described in which data of AFC-LOG 113 is renewed once at a predetermined time every day during one month. However, the present invention is not limited to this, and other various renewal methods for AFC-LOG 113 can be adopted.

When the control voltage Vc is obtained and recorded, it is desired that temperature is stable. Further, the more temperatures recorded at

times of obtaining a plurality of pieces of data are varied, the higher the precision in the approximation for the data can be.

Therefore, for example, at least one of following exemplary conditions 1 to 4 is arbitrarily selected, and the control voltage  $V_c$  is obtained when the selected exemplary condition(s) is/are satisfied. In this case, pieces of data set to a stable and stationary state at varied temperatures can be obtained.

(Exemplary condition 1) The temperature  $T_e$  is observed every ten minutes, and the temperature change is less than  $1^{\circ}\text{C}$ . When this condition is satisfied, it is expected that temperature has reached the stationary state.

(Exemplary condition 2) Electric power is supplied after the power off state of the mobile terminal is continued for one hour or more, and the data obtaining time is just after a signal transmitted from a base station can be received. In this condition, pieces of data at comparatively low temperatures before increasing temperature can be obtained.

(Exemplary condition 3) The mobile terminal is set in the standby state for one hour. When this condition is satisfied, it is expected that temperature is placed in the stationary state.

(Exemplary condition 4) The mobile terminal continues data transmission for ten minutes or more. In this condition, because a power amplifier is heated, the temperature of the oscillator is heightened, and pieces of data at high temperatures can be obtained. The high temperature denotes a temperature near to an upper limit temperature at which the mobile terminal can be normally operated.

Further, when data of an obtained control voltage  $V_c$  becomes old, the secular change cannot be disregarded. Therefore, data obtained a predetermined period of time or above ago may be deleted according to the

time information recorded in AFC-LOG 113, or the data may be removed when the secular change correction data DVcomp is calculated by processing unit 206.

Furthermore, there are various calculation methods of the secular  
5 change correction data DVcomp and various renewal methods of AFC-LOG  
113. One of the methods can be arbitrarily selected, or one of the  
calculation methods and one of the renewal methods can be arbitrarily  
combined.

While preferred embodiments of the present invention have been  
10 described using specific terms, such description is for illustrative purposes  
only, and it is to be understood that changes and variations may be made  
without departing from the spirit or scope of the following claims.